Temporal evolution of proto-Izu-Bonin-Mariana arc volcanism: Constraints from statistical analysis of melt inclusion composition

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International Ocean Discovery Program (IODP) Expedition 351 “Izu-Bonin-Mariana (IBM) Arc Origins” drilled Site U1438 into volcaniclastic sediments deposited immediately after subduction initiation and inception of arc volcanism at the north-western margin of the Philippine Sea plate 52 million years ago. From the drill cores, we have recovered melt inclusions hosted in fresh silicate minerals (augite and plagioclase) and analyzed their major, trace and volatile element composition of 304 melt inclusions from Unit III (30-40 Ma) at Site U1438 in Amami Sankaku Basin. This provides us a record the magmatic evolution of the proto-IBM arc between 30 and 40 Ma (Brandl *et al.*, 2017). The melt inclusions are diverse in composition, ranging from low- to high-K series basaltic through rhyolites. Brandl *et al.* (2017) concluded that (i) the volcanism of proto-IBM arc shifted from calc-alkaline to tholeiitic over time and (ii) such shift is linked to both the volcanic productivity and maturation of the island arc volcanism.

Recently, we have extended the dataset of Brandl *et al.* (2017) by (i) additional analysis of four volatile elements (H_2O, S, Cl and F) and non-volatile P_2O_5 for 55 selected melt inclusions by Secondary Ion Mass Spectrometry (SIMS) at Kochi Institute for Core Sample Research of JAMSTEC and (ii) statistical analysis on the geochemical composition of 236 selected melt inclusions in order to separate them into several, petrologenetically distinct groups. Among methods of statistical analysis, we performed Principal Component Analysis and K-means Cluster Analysis on the 236 melt inclusions to make full use of the geochemical data of the major elements (10 elements) and the volatiles (S and Cl), following the procedures of Iwamori *et al.* (2017).

Combined with (i) and (ii), the melt inclusions can be grouped into seven clusters termed Clusters 1 to 7, mainly based on characteristics of elements of lower concentration, such as K_2O, TiO_2, S and Cl (Fig. *a*-*d*), indicating seven distinct magmatic activities. The cluster numbers are assigned in the order of the mean values of SiO_2; the mean value of SiO_2 is the lowest for Cluster 1 and that is the highest for Cluster 7. Cluster 1 melt inclusions (n=63) are medium-K series rocks characterized by relatively high S concentrations (500-3,000 ppm) and define calc-alkaline trends. Cluster 2 melt inclusions (n=64) are medium-K tholeiites charecterized by high TiO_2 (>0.8 wt.%). Cluster 3 melt inclusions (n=9) contain extremely high Cl concentrations (up to 1 wt.%). Cluster 4 melt inclusions (n=31) are high-Mg andesites. Melt inclusions assigned to Cluster 6 (n=19) and Cluster 7 (n=5) are silicic. Identification of subgroups of melt inclusions as summarized here cannot be made by conventional graphical approach using two-dimensional diagrams, demonstrating the usefulness of introducing statistical approaches into geochemistry.

The Cluster 5 melt inclusions (high-Mg andesites) emerge from 40 Ma and fades out at 35 Ma, while melt inclusions assigned to Cluster 2 (medium-K tholeiites) and Cluster 4 (low-K tholeiites) emerge from 38 Ma and last until 30 Ma (Fig. *e*). We interpret that the disappearance of Cluster 5 melt inclusions is linked to the occurence of melt inclusions assigned to Cluster 2 and Cluster 4 which represent normal arc volcanism of tholeiitic magmas. Assuming such a transition in volcanism at age interval of 35 to 38 Ma would be attributed to crustal thickening as the proto-IBM arc evolves by continuous addition of deep basaltic magmas (e.g., Tamura *et al.*, 2016).

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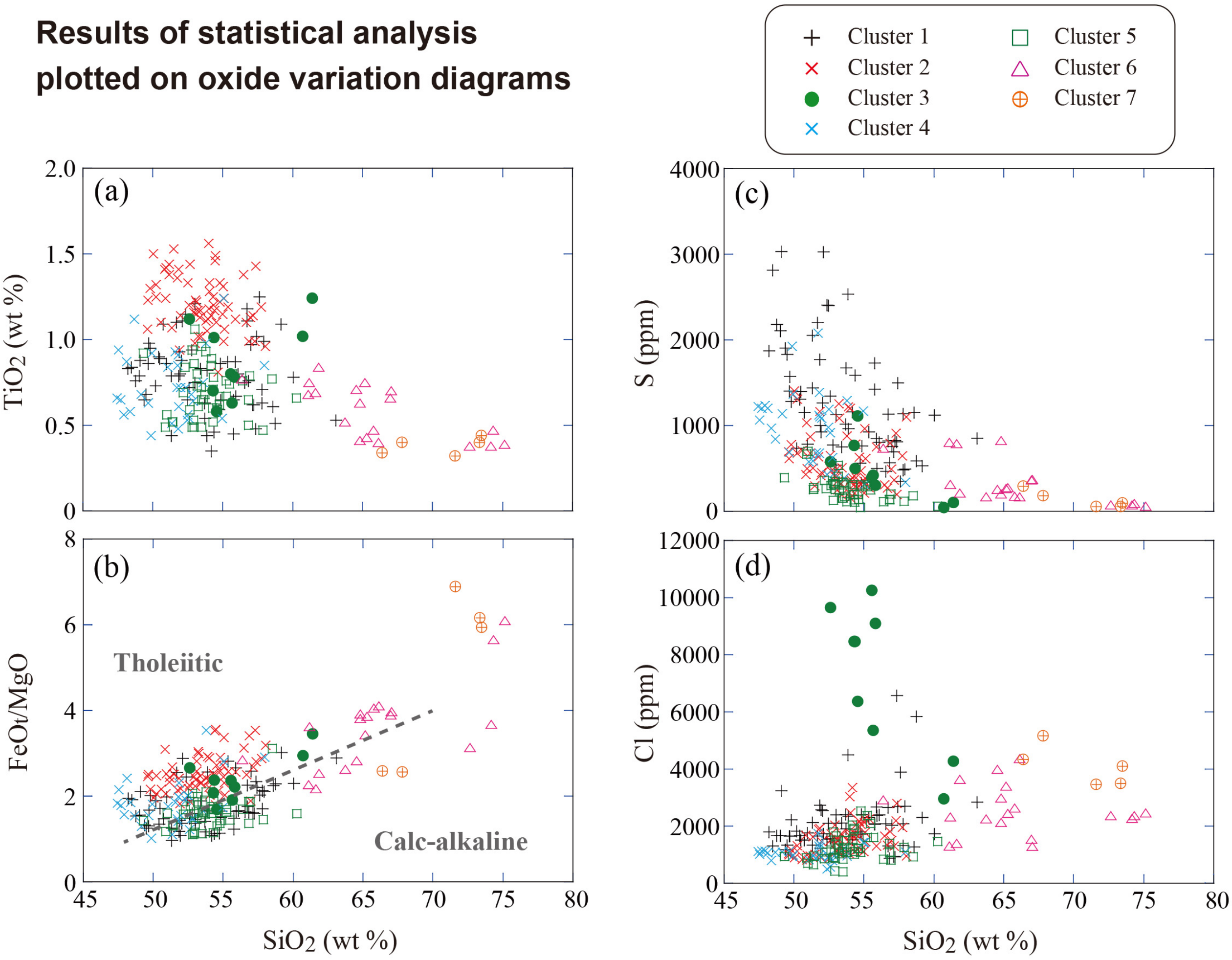
Results of statistical analysis plotted on oxide variation diagrams



(e) **Overview of the occurence of each cluster with age**